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Spatial Distribution Pattern and Risk Analysis of Rodent Damage in Artificial Chinese Fir Forests

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Abstract: As an important production area of Chinese fir (*Cunninghamia lanceolata*) in southern China, Guangxi is severely threatened by rodent damage in artificial Chinese fir forests. It is urgent to clarify the spatial pattern and risk level of rodent damage to support scientific prevention and control. This study took young artificial Chinese fir forests as the research area to explore the spatial distribution pattern of rodent damage and evaluate the rodent risk levels. Damaged trees were manually identified based on UAV orthophotos, spatial pattern analysis was conducted using ArcGIS, and a multi-index comprehensive evaluation method was adopted to analyze the risk of rodents. The results showed that: (1) The rodent-damaged Chinese fir plants in the research area presented a significant aggregated spatial distribution pattern (R=0.553); (2) Risk assessment classified *Mus musculus* (house mouse), *Rattus norvegicus* (brown rat), and *Microtus fortis* (reed vole) as medium-risk species, and *Rattus losea* (rice field rat), *Rattus tanezumi* (roof rat), *Callosciurus erythraeus* (Pallas's squirrel), and *Rhizomys sinensis* (Chinese bamboo rat) as low-risk species. In conclusion, management countermeasures are proposed by combining the spatial distribution pattern and risk levels, which provide a scientific basis for the precise prevention and control and sustainable management of rodent damage in Chinese fir forests in Guangxi.

Keywords: Artificial Chinese fir forest; Rodent; Spatial distribution pattern; Risk analysis

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1. Introduction

Guangxi is a major production area of Chinese fir (*Cunninghamia lanceolata*) in southern China, and the healthy management of artificial Chinese fir forests is of great significance to regional economic development and ecological security. However, the continuous expansion of rodent populations in forest areas poses a severe threat to the survival and growth of young artificial Chinese firs. Rodents gnaw on tree bark, rhizomes, and other parts, leading to stunted growth or death of trees and causing direct economic losses. To achieve scientific and effective rodent management, accurately grasping the spatial distribution pattern of their damage and clarifying the risk levels of different rodent species are the primary prerequisites.

Traditional field survey methods have limitations in obtaining large-scale and continuous spatial data. UAV remote sensing technology, with its flexibility and high-resolution characteristics, provides a new solution for the study of the spatial distribution of forest pests. Combined with the GIS spatial statistical analysis function, the spatial distribution pattern can be accurately analyzed. In terms of risk management, the *Criteria for Risk Analysis of Forest Pests* (LY/T 2588-2016) provides a basis for the quantitative risk assessment of forest pests.

This study analyzed the spatial distribution pattern of rodent damage through remote sensing technology; identified the main rodent species damaging Chinese firs in Guangxi and evaluated their risk levels through literature research; and proposed management countermeasures based on the comprehensive results of spatial pattern and risk analysis, providing a basis for the precise prevention and control and sustainable management of rodent damage in Chinese fir forests.

2. Materials and Methods

2.1. Study Area Overview

The study area is located in the teaching and experimental forest farm of Guangxi Eco-Engineering Vocational and Technical College in the Northern Ecological New Area of Liuzhou City, Guangxi Zhuang Autonomous Region, dominated by gentle hills with an average altitude of 142 m. It has a subtropical monsoon climate with an annual average temperature of 20.5°C, an annual average precipitation of 1,450 mm, an annual average sunshine duration of 1,634.9 h, and a frost-free period of 314 days. The total forest planting area of the study area is 990.4 hm^2, with a forest stock volume of 165,000 m^3 and a forest coverage rate of 85.5%, among which the total Chinese fir planting area is 101.29 hm^2.

A reconnaissance survey of the teaching and experimental forest farm was conducted in September 2024, and sample plots were set up in the young Chinese fir forest planting area of the forest farm for investigation in March 2025.

2.2. Spatial distribution pattern of rodent damage

2.2.1. Image acquisition and processing

Based on the reconnaissance survey, a 3-year-old young Chinese fir forest plot (≈8.52 hm^2) damaged by rodents was selected as the study sample plot. Six investigators conducted a survey from the foot to the top of the mountain, identified whether the damage was caused by rodents by distinguishing tooth marks at the base of tree trunks and residual bark debris on the ground, and hung red plastic marker plates on the crown tops of damaged trees (**Figure 1**).

A DJI M4E UAV was used to conduct aerial photography of the study area at a flying height of 100 m relative to the photographed target. Pix4Dmapper was used to generate the Digital Orthophoto Map (DOM) of the study area, which was imported into ArcGIS 10.8. Damaged Chinese firs were manually identified and marked to construct a spatial distribution point layer of damaged trees.

Figure 1. Rodent-damaged Chinese firs marked with red plastic plates

2.2.2. Nearest neighbor analysis

The Average Nearest Neighbor Index (NNI) was used to determine the spatial pattern and calculate the nearest neighbor index R. If R=1, the distribution pattern is random; if R<1, the pattern is aggregated; if R>1, the pattern tends to be dispersed. The calculation formula is as follows:

$$R = \frac{\overline{d}_{min}}{E(d_{min})} = \frac{\sum_{i=0}^{n}}{0.5\sqrt{A/n}}$$

Where: d_i is the distance between the i-th damaged plant and its nearest damaged neighbor; A is the area of the study region; n is the number of damaged plants; $d_{\min}$ is the average of the nearest neighbor distances of damaged plants; $\overline{d}_{\min}$ is the average value that gives the actual closest distance; $E(d_{\min})$ is the theoretical average nearest neighbor distance under the random distribution pattern.

2.3. Rodent risk analysis

2.3.1. Establishment of a quantitative evaluation index system for pest risk

A comprehensive evaluation index system was established and scored from five aspects: pest distribution (*P1*), possibility of spread and diffusion (*P2*), potential harmfulness (*P3*), importance of damaged host (*P4*), and management difficulty (*P5*).

2.3.2. Calculation formula for quantitative analysis of pest risk

$$P_1 = P_{11}$$

$$P_2 = \sqrt[5]{P_{21} \times P_{22} \times P_{23} \times P_{24} \times P_{25}}$$

$$P_3 = 0.4 \times P_{31} + 0.4 \times P_{32} + 0.2 \times P_{33}$$

$$P_4 = Max(p_{41}, p_{42}, p_{43})$$

$$P_5 = (p_{51} + p_{52} + p_{53})/3$$

Risk value R:

$$R=\sqrt[5]{P_1 \times P_2 \times P_3 \times P_4 \times P_5}$$

2.3.3. Classification standard for risk value R

$2.5 \leq R < 3.0$: Extreme risk; $2.0 \leq R < 2.5$: High risk; $1.5 \leq R < 2.0$: Medium risk; $1.0 \leq R < 1.5$: Low risk.

2.4. Data analysis

ArcGIS 10.8 was used to analyze the average nearest neighbor index, and Microsoft Excel 2019 was used to calculate the quantitative pest risk values.

3. Results and analysis

3.1. Spatial distribution pattern of rodent damage

The Average Nearest Neighbor tool in ArcGIS 10.8 was used to quantitatively evaluate the spatial distribution pattern of rodent-damaged Chinese firs in the sample plot, and the Nearest Neighbor Index R was obtained (**Table 1**). A total of 254 damaged Chinese firs were recorded in the study area, with an observed average nearest neighbor distance of 2.616 m and an expected average distance of 4.733 m. The calculated nearest neighbor index R=0.553 (R<1), Z=-13.636 (far less than -2.58), and the corresponding P-value was close to 0 (P<0.01). The results indicated that the spatial distribution of rodent-damaged Chinese firs in the study area showed a significant aggregated pattern.

Table 1. Nearest neighbor index of damaged plants

Number of damaged plants	Observed average nearest neighbor distance/m	Expected average nearest neighbor distance/m	Nearest Neighbor Index (*R*)	Z-value	*P*-value	Distribution pattern
254	2.616	4.733	0.553	-13.636	0	Aggregated

3.2. Rodent risk analysis

3.2.1. Domestic and foreign distribution (P1)

The main rodent species damaging Chinese firs in Guangxi include *Rattus losea* (rice field rat), *Rattus tanezumi* (roof rat), *Mus musculus* (house mouse), *Rattus norvegicus* (brown rat), *Microtus fortis* (reed vole), *Callosciurus erythraeus* (Pallas's squirrel), and *Rhizomys sinensis* (Chinese bamboo rat) [1–3]. The domestic and foreign distribution of these rodents is shown in **Table 2**.

Table 2. Main rodent species damaging Chinese firs in Guangxi and their distribution

Species	Domestic distribution	Foreign distribution
Rattus losea	Guangxi, Guangdong, Fujian, Hainan, Zhejiang, Jiangxi, Anhui, Hunan, Guizhou, Yunnan, Sichuan	Vietnam, Thailand, Myanmar, Cambodia, Laos, Malaysia, Singapore, India, Bangladesh, Nepal, Bhutan
Rattus tanezumi	Southern provinces of China	Afghanistan, Bhutan, Cambodia, India, Japan, North Korea, South Korea, Malaysia, Thailand, Vietnam, Myanmar, Nepal, South Africa, Kenya, Tanzania
Mus musculus	Nationwide in China	Global (except Antarctica)
Rattus norvegicus	Nationwide in China	Global (except Antarctica)
Microtus fortis	Guangxi, Guangdong, Hunan, Hubei, Jiangxi, Anhui, Jiangsu, Zhejiang, Fujian, Yunnan	North Korea, South Korea, Japan, Vietnam, Laos, Cambodia, northern Myanmar
Callosciurus erythraeus	Guangxi, Guangdong, Yunnan, Guizhou, Hainan, Fujian, Taiwan, Zhejiang, Jiangsu, Anhui, Henan, Jiangxi, Hubei, Hunan, Sichuan	Myanmar, India, Bhutan, Thailand, Cambodia, Laos, Vietnam, Malaysia, Nepal, Bangladesh
Rhizomys sinensis	Guangxi, Guangdong, Fujian, Yunnan, Guizhou, Sichuan, Hunan, Hubei, Jiangxi, Anhui, Zhejiang	Northern Myanmar, Vietnam, Laos, northern Cambodia, northeastern India, Bangladesh

3.2.2. Possibility of spread (P2), potential harmfulness (P3) and management difficulty (P5) of rodents

Callosciurus erythraeus spreads through continuous jumping and movement in the forest canopy [4]. This squirrel gnaws on the main shoots of Chinese firs and even causes girdling of tree trunks in severe cases. Its capture rate by ground baiting and rat traps is extremely low, and control measures such as smearing repellents on tree trunks and binding control devices are required, which are costly and inefficient in operation [5].

Rhizomys sinensis slowly expands to the surrounding areas by digging burrows underground [6]. This bamboo rat gnaws on Chinese fir stems in mixed bamboo-fir forests or when food is scarce. Conventional monitoring methods cannot detect the signs of its damage in a timely manner [6]. At present, control mainly relies on setting snares and digging burrows [7]. Due to its mountainous habitats with poor transportation, the control cost is high.

Rattus norvegicus can spread over long distances by means of human transportation, with a fast population growth rate and the ability to quickly occupy habitats. It is omnivorous, often digs burrows in forest lands and field ridges, and gnaws on seedlings, bark, and roots. Control measures include setting isolation belts, removing weeds, and placing poison baits. This rat is large in size and highly active, resulting in relatively high control difficulty.

Microtus fortis has a significant population fluctuation cycle and can quickly spread to new suitable habitats when conditions are favorable [8]. It gnaws on the bark at the base of Chinese firs and causes girdling in winter when food is scarce [9]. Control measures include improving forest land drainage and placing poison bait belts [10]. Its population dynamics are affected by food, natural enemies, and other factors, making it difficult to accurately predict outbreak times.

Mus musculus has an extremely high reproductive rate, enabling its population to establish and expand rapidly in a short time [11]. This mouse bites off the tender stems of Chinese fir seedlings and gnaws on the bark at the lower part of young forest trunks, but the gnawed area is small, rarely causing girdling, and most wounds are spot-shaped or strip-shaped. Control measures include removing surrounding weeds and placing bromadiolone [12]. Due to its small size and hidden habitats, it is difficult to completely eradicate.

Rattus tanezumi is good at climbing, can move between buildings and trees, and spreads over long distances by means of transportation. It gnaws on the bark at the middle and upper parts of tree trunks and even branches, with irregular sheet-shaped gnaw marks, which in turn leads to the death of branches [13]. Anticoagulant rodenticides are used for control in production, but their habitats in the upper part of buildings or on tree trunks increase the difficulty of baiting and cleaning [14].

Rattus losea inhabits humid environments, and its populations spread from farmlands to adjacent Chinese fir forests after crop harvesting [15]. This rat gnaws on the bark at the base of Chinese firs in winter [16]. Control measures in production include removing weeds at forest edges and placing anticoagulant rodenticides [17]. Due to its diverse habitats and the interlacing of farmlands and forests, the control range is wide, and continuous control is required.

3.2.3. Economic and ecological importance of Chinese Firs (P4)

Chinese fir, a general term for *Cunninghamia* in the Taxodiaceae family, is a unique native fast-growing and precious tree species in China, as well as a dominant tree species in collective forest areas in southern China, and one of the most important commercial timber tree species in China.

Chinese fir has now become a strategic tree species for ecological restoration and timber supply in the mountainous areas of southern China. At present, the area of artificial Chinese fir forests in China is about 11.5 million hm^2, with a stock volume of 1.98 billion m^3 and a commercial timber output of 115 million m^3, mainly concentrated in humid mountainous areas in southern China such as Fujian, Hunan, and Jiangxi [18]. The area of Chinese fir forests in Guangxi is about 1.5038×10^6 hm^2 with a stock volume of 1.29×10^8 m^3 [19]. Chinese fir not only promotes the sustainable development of Guangxi's commercial forest industry, but also balances ecological environmental protection and economic development, which is of important strategic significance for giving full play to the advantages of Guangxi's forestry resource endowment and consolidating the foundation of national timber security.

3.2.4. Quantitative risk analysis of rodents in Guangxi

Combined with the literature and the standard LY/T 2588-2016, the risk assessment results were obtained (**Table 3**).

There were 0 extreme/high-risk rodent species, 3 medium-risk species: *Mus musculus* (*R*=1.81), *Rattus norvegicus* (*R*=1.52), *Microtus fortis* (*R*=1.78), and 4 low-risk species: *Rattus losea*, *Rattus tanezumi*, *Callosciurus erythraeus*, *Rhizomys sinensis*.

Table 3. Score of evaluation indexes and risk grade of rodents damaging Chinese firs in Guangxi

Species	P_{11}	P_{21}	P_{22}	P_{23}	P_{24}	P_{25}	P_{31}	P_{32}	P_{33}	P_{41}	P_{42}	P_{43}	P_{51}	P_{52}	P_{53}	R	Risk grade
Rattus losea	0.5	1	2	2	2	2.5	1.5	1.5	0.5	0.5	2.5	2.5	1.5	0.5	2.5	1.35	Low
Rattus tanezumi	0.5	1.5	2.5	2.5	2.5	2.5	2	1.5	0.5	0.5	2.5	2.5	1.5	0.5	2.5	1.45	Low
Mus musculus	1.5	2	2.5	2.5	2	2.5	2	1.5	0.5	0.5	2.5	2.5	1.5	0.5	2.5	1.81	Medium
Rattus norvegicus	0.5	2	2.5	2.5	2	2.5	2.5	2	0.5	0.5	2.5	2.5	1.5	0.5	2.5	1.52	Medium
Microtus fortis	2	0.5	1.5	2	1.5	2.5	2.5	2	0.5	0.5	2.5	2.5	1.5	0.5	2	1.78	Medium
Callosciurus erythraeus	0.1	1	1	2	2.5	2.5	2.5	2.5	0	0.5	2.5	2.5	1	2	2.5	1.09	Low
Rhizomys sinensis	0.1	0.1	0.5	1.5	0.5	1.5	1.5	1	0	0.5	2.5	2.5	1.5	1.5	1.5	0.73	Low

4. Management countermeasures

For medium-risk rodent species, an ecological intervention-oriented strategy supplemented by chemical agents should be implemented: reduce forest stand canopy density through thinning during the breeding period, set up biological isolation belts simultaneously, and supplement with intelligent monitoring and early warning. For low-risk rodent species, natural regulation by natural enemies should be relied on; forest edge shrubs should be retained to maintain ecological balance, and only local repellent measures should be taken when rodent density is abnormal.

For aggregated damage areas, forest stand structure transformation should be prioritized to improve the system's stress resistance through coniferous-broadleaved mixed planting; habitat regulation should be strengthened in buffer zones, and litter and stumps should be cleaned to destroy rodent hiding places; the outer areas should focus on monitoring, and artificial transmission paths should be blocked, combined with seedling quarantine.

Strip thinning should be implemented in continuous pure forests to form an uneven-aged and multi-layered structure; ditches should be dug for drainage in low-lying plots to reduce soil moisture and inhibit the reproduction of moisture-loving rodents; native shrub patches should be retained to provide habitats for natural enemies. Through systematic transformation, the shift from passive control to active ecological regulation is realized.

5. Conclusions and discussion

Through ArcGIS nearest neighbor index analysis and rodent risk assessment, this study clarified the spatial pattern of rodent damage and risk levels of rodent species in Chinese fir forests: the rodent-damaged Chinese fir plants in the study area showed a significant aggregated distribution, reflecting the existence of local high-density damage centers caused by the ecological habits of rodents such as colonial nesting and foraging; the division of rodent risk levels into high, medium and low grades realized the precise matching of damage degree and control resources. This grading strategy not only improves control efficiency but also reduces the abuse of chemical agents.

This study only revealed the spatial pattern and risk levels at the current scale. In the future, long-term dynamic monitoring should be carried out, the monitoring scale should be expanded combined with remote sensing technology, the balancing effect of natural enemies should be quantified, and field verification of ecological regulation technologies in aggregated damage core areas should be conducted to optimize the practicability of control measures, providing scientific support for the healthy and sustainable development of Chinese fir forests in southern China.

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Disclosure statement

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